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TECOM Project No. 7-CO-R87-EPO-006

TEST REPORT

OF

INTRUSION DETECTION SYSTEM METHODOLOGY INVESTIGATION

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MEMORANDUM FOR: Commander, U.S. Army Electronic Proving Ground, ATTN: STEEP-DT-E

SUBJECT: Methodology Investigation Draft Final Report, TECOM Project No. 7-CO-R87-EPO-006

1. Subject report is approved.

2. Point of contact, this headquarters, is Mr. Richard Haire, AMSTE-TC-M, amstetcm@apg-4.arpa, AV 298-2170/3677.

FOR THE COMMANDER:

Grover H. Shelton

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The author would like to thank Brian Desind, Stan Orrell and Paula Metzner of EG&G Energy Measurements Group, Kirtland Operations, Kirtland AFB, Albuquerque, New Mexico, for their work on this study. EG&G was asked to conduct this study because of their prior experience with vibration phenomena.

SECTION 1. SUMMARY

1.1 **Background**. There currently exists a performance deficiency in the testing of the Facility Intrusion Detection System (FIDS) vibration sensor. Specifically, a reliable and repeatable method for testing the higher frequencies (up to 15 kHz) covered by the sensor does not exist. The major difficulty is in finding an exciter mechanism (e.g., shake table) that can handle the combination of high frequency and acceleration necessary. The problem is exacerbated by the desirability of testing the entire sensor as a unit instead of just its transducer. This increases the mass that must be accelerated and constrains the physical connection between the tester and sensor.

The specification for the FIDS vibration sensor (VS) states that it will alarm on 0.01g or more of acceleration in any one of four switch selectable frequency bands, 2.76 - 7.76 kHz, 4.08 - 9.08 kHz, 6.27-11.27 kHz or 10.65 - 15.65 kHz. Therefore, any test fixture for the VS must be capable of generating at least 0.01g from approximately 2 - 16 kHz.

An additional requirement for the test fixture is that it fit inside an environmental chamber so that the vibration sensor can be tested across its full rated temperature range of -40°C - +65°C. Although the environmental chamber in which a test fixture will most likely be used measures 11' x 17' x 10' it is desirable that the fixture be considerably smaller for two reasons. First, because of the high cost and length of time to run environmental tests it is often necessary to test several sensors at one time. Therefore, no one test fixture can occupy the entire chamber. Second, a small test fixture would have wider application because it could fit in smaller environmental chambers. This would require that the fixture not dissipate excessive heat such that it overwhelms the capacity of a smaller chamber.

EG&G Energy Measurements Group, Kirtland Operations, was tasked to do this study because of their experience with the FIDS vibration sensor and their prior studies of vibration phenomena. These studies included an analysis of the performance of the piezoelectric sensing element used in the FIDS vibration sensor, the vibration effects produced by penetration attempts in concrete structures and the design of a transducer with greater sensitivity to acceleration than the FIDS transducer.

1.2 **Objectives**. The objectives of this study were to:

1. Select an excitation method for testing the FIDS vibration sensor
2. Design a fixture based on this method
3. Use the fixture to determine
   a. feasibility and practicality of the excitation method
   b. critical features which affect test repeatability

The effort summarized in this report addresses only a portion of the design necessary for a complete test fixture, namely, the design considerations for an "exciter", including requisite fixturing, which could be used to produce and couple vibratory energy into the sensor under test. It was not an objective of this study to produce a finalized test fixture ready for end item testing.

1.3 Summary of Procedures. Three possible methods of exciting the FIDS vibration sensor are impulse force (shock), shaker table and small exciter. The small exciter method was chosen as the most promising for further investigation because of its low cost, simplicity and because work done by EG&G prior to this study had produced a likely candidate for the exciter element.

A description of the FIDS vibration sensor transducer is given in order to understand the design features of the test fixture. The test fixture based upon the small exciter was made up of a mounting system for the vibration sensor, the localized exciter and the equipment used to generate and analyze the test signals to the exciter. The mounting system consisted of an aluminum block hard mounted to the sensor's transducer plate. The mass of the block reduced the effects of the transducer plate's internal resonances on the system response. Resonances caused by the flanges on the transducer plate and by the sensor enclosure were damped by using a gasket between the sensor and the mounting block.

The operation of the exciter, like the vibration sensor, is based upon a piezo-electric ceramic element. In the exciter, the piezo-electric element was driven by a voltage to produce vibrational output. The exciter was pressed against the sensor by a stiff spring through a hole in the mounting base, thereby providing a tight coupling. The exciter was driven by a test signal which was swept from 0 to 20 kHz. The output of the vibration sensor transducer was displayed on a spectrum analyzer. This output was used to identify any spurious test fixture/vibration sensor system resonances.

Foam and rubber gaskets in different thicknesses were used between the vibration sensor and the mounting base. For each gasket material and thickness the system transfer function was examined to determine the efficacy of the gasket in damping spurious resonances. The spring used to hold the exciter was also damped after it was identified as a possible source of resonances.

1.4 Summary of Results. The foam material produced a system response which had a peak at 14 kHz with a local peak at 6 kHz. Also, the response was not smooth but jagged. The response with a single layer of the rubber gasket had many peaks and nulls and was even more jagged than the response of the foam. With two layers of rubber gasket the response curve was much smoother than either previous case although there was still a peak around 14 kHz and local peaks at 2 and 4 kHz.

When the spring was dampened with foam the local peaks at 2 and 4 kHz previously described were severely attenuated and a smooth response achieved. The peak at 14 kHz which was observed to a greater or lesser extent in all the configurations did not correlate to the different gasket materials used but rather changed amplitude whenever the sensor was remounted on the test fixture.

1.5 **Analysis**. There are two characteristics of the gasket material which affect the output response of the test fixture/vibration sensor system; stiffness and thickness. When the sensor is bolted to the test fixture the gasket is compressed and its original thickness and stiffness determine the force it applies to the sensor to damp spurious resonances. Its stiffness also affects how well the gasket can conform to irregularities on the surfaces of the sensor and mounting base and better damp these irregularities.

The test results with the black foam and the rubber gaskets demonstrates the effects of these two characteristics. The foam, although thicker than the double layer of rubber gasket, did not damp resonances as well because it was not stiff enough. On the other hand, the single layer of gasket fared worse than the foam because it was not thick enough. Any evaluation of potential gasket materials must take into consideration both of these parameters.

As was demonstrated with the gasket testing, undamped mechanical resonances are a major factor affecting the system response. Proper choice of gasketing material will attenuate the resonances associated with the sensor but there are other sources that must be dealt with. In general, any part of the test system which has good mechanical contact with the sensor's transducer or the exciter can contribute unwanted resonances. This was graphically illustrated by the response curves before and after damping the spring. The two resonances at 2 and 4 kHz which were attenuated by this were directly attributable to the spring.

As the response curve obtained after the spring was damped showed, it is possible to obtain a relatively flat response over the frequency range of the FIDS vibration sensor. It has only been shown as a possibility, however, because as far as minimizing the peak at 14 kHz was concerned, this result was not repeatable. More work will be necessary to identify the cause of the 14 kHz peak and eliminate it.

1.6 **Conclusions**. The results of this study indicate the following:

1. A small exciter design is a feasible method of stimulating the FIDS vibration sensor because it:

a. has a frequency response greater than the FIDS vibration sensor's range
b. results in a small test fixture able to fit in an environmental chamber
c. can couple enough energy into the vibration sensor
d. is low cost and simple to construct

2. Critical areas in test fixture design are:

   a. Undamped mechanical resonances
      1. cause non-uniform system response
      2. sources: flanges on transducer plate, sensor mounting hardware, edges of sensor enclosure, enclosure fasteners (screws), internal resonances in mounting base, spring and other hardware used to press exciter against sensor
      3. proper damping can attenuate these resonances to acceptable levels

   b. Coupling between exciter and sensor
      1. surfaces of transducer plate and exciter must be clean and smooth
      2. a coupling fluid should be applied between the transducer plate and exciter which has low viscosity, high persistence and which doesn't form bubbles or an air space (e.g. octyl-alcohol or kerosene)
      3. exciter mounting plate should be steel instead of aluminum for higher resistance to damage

1.7 Recommendations. The scope of this study did not include designing a complete vibration sensor test fixture but rather focused on the method of excitation. To complete the design of a test fixture the following areas need further work:

1. Gasketing material
   Neither of the two materials used in this study was ideal. The black foam was not stiff enough and the rubber was too stiff. What is needed is a material which is stiff enough to damp spurious resonances yet compliant enough to conform to any irregularities in the surfaces of the vibration sensor or mounting base. Testing for this material will also have to identify the proper thickness of material needed to achieve adequate damping.

2. Mounting base
   The aluminum mounting base used in this study provided a large mass to shift the internal resonances of the transducer plate out of the sensor's pass band. However, aluminum does not have a high internal friction and therefore does not attenuate any of these resonances. A material like wood or bakelite has

higher internal friction and would act to damp resonances.

3. Sensor mounting

This study did not resolve the problem of why the level of the response changed when the sensor was remounted on the fixture. The feature of the sensor mounting scheme that is responsible will have to be identified and eliminated. It is possible that successful results from the tests for a new gasket and mounting base might solve this problem but if not then some more repeatable method of mounting the sensor will have to be found.

SECTION 2. DETAILS OF INVESTIGATION

2.1 Selection of vibrational excitation method. In order to functionally test a device, the device's response to a known stimulus must be measured. This implies the existence of a repeatable, well-defined stimulus.

In the case of the VS transducer, the most obvious choice for a stimulus would be a mechanical force normal to the surface of the mounting plate. The possibilities include:

- impulse force (shock) applied by a ballistic device
- steady-state vibration provided by a massive, rigidly coupled exciter, such as a shaker table
- steady-state vibration provided by a rigidly coupled, but small and lightweight exciter.

2.1.1 Impulse. Impulse response measurements are a standard method of characterizing electrical systems, and are quite reasonable for use in mechanical systems as well. These techniques, however, usually require fairly expensive, sophisticated equipment, such as FFT analyzers, and would be unsuitable for field use. Impulse response tests of the VS transducer were performed at EG&G, using an in-house shock-test apparatus, as a way of confirming data collected by other means.

2.1.2 Steady-state. Steady-state measurements require a stable, controlled excitation source within the amplitude and frequency range of interest. While the VS transducer itself is responsive to signals well over 20 kHz, the VS electronics limits the region of interest to frequencies between approximately 2 kHz and 16 kHz. An exciter is required which can stimulate the transducer throughout this range of frequencies, without producing spurious vibrations in the transducer mounting plate or other parts of the VS assembly, and without introducing significant coloration of its own.

2.1.2.1 Shaker table. A massive shaker table would fulfill this role ideally. The VS transducer mounting plate could be rigidly affixed to the shaker platform, and the large mass of the platform would provide a low driving impedance. This is not, however, an ideal solution since a shaker table capable of producing sufficient excitation over the entire VS range would be prohibitively large and expensive.

2.1.2.2 Small exciter. An alternative method of providing steady-state excitation is the use of a small, lightweight exciter. This exciter, even with a smaller mass than the VS transducer itself, could apply a localized excitation, and the drive requirements would thus be modest.

Because of its potentially lower cost and simplicity, the small, localized exciter concept was chosen as the most promising for further investigation. Additionally, work done previous to this study had developed a more sensitive vibration transducer which would be a likely candidate for the exciter.

2.2 Test fixture description.

2.2.1 Mounting fixture.

2.2.1.1 Description of FIDS VS transducer. In order to discuss the design of the test fixture it is necessary to describe the construction of the current model FIDS VS transducer (see fig. 1). This figure shows the VS transducer as installed in a typical VS enclosure, using a formed rubber gasket to separate the transducer from the enclosure. The mounting plate is 3/8" thick, except around its perimeter, where the thickness is reduced to 1/8" forming a flange. Not shown in the figure are the studs for electrical connection to the transducer.

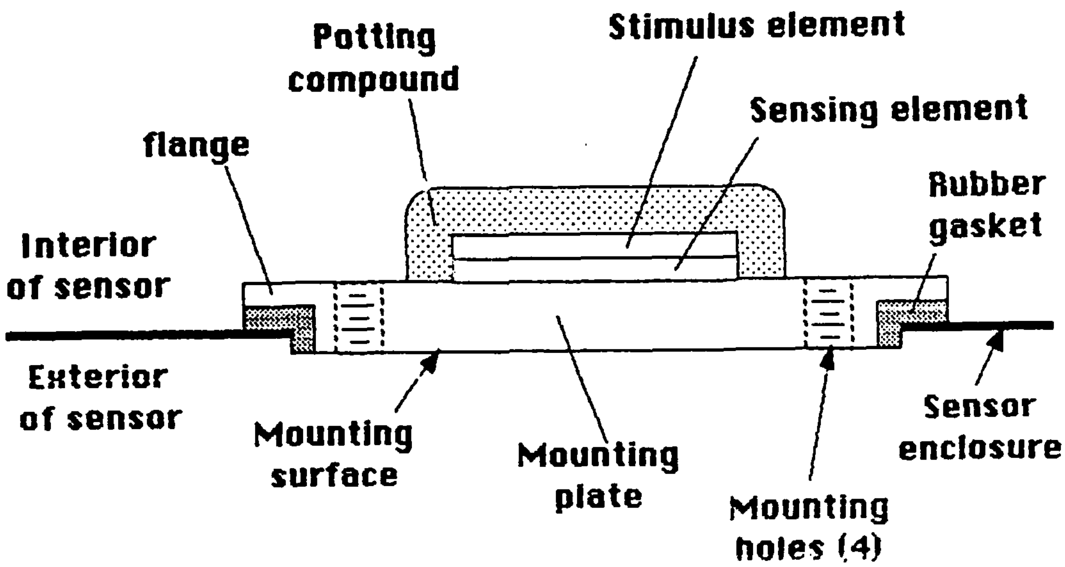


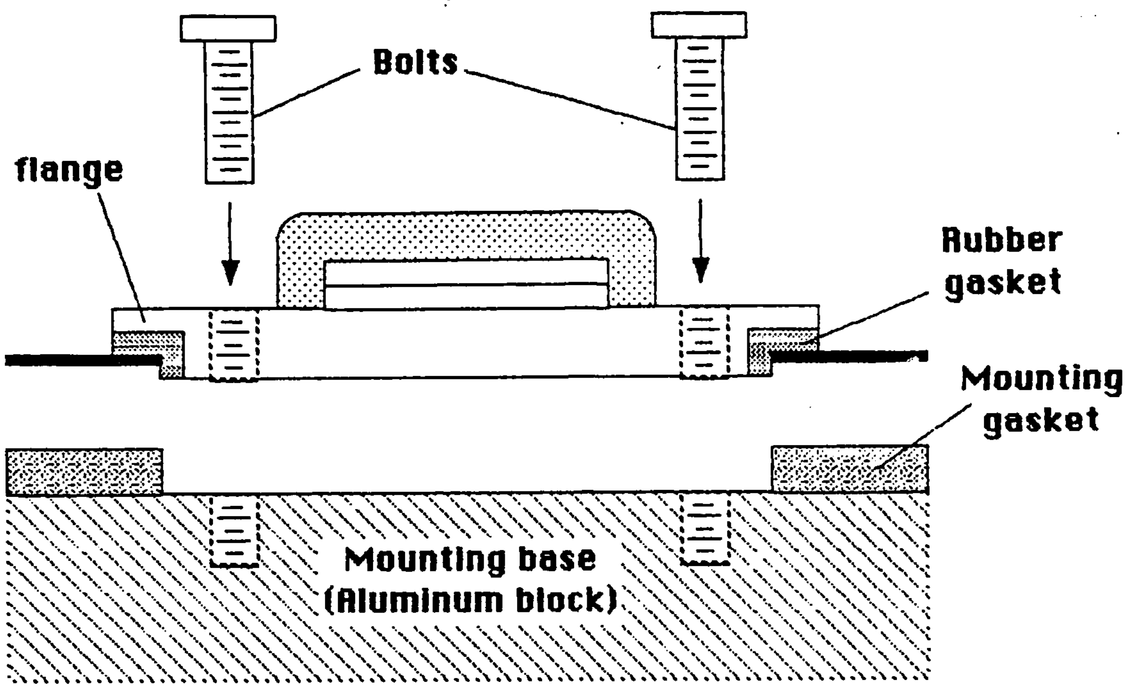
Figure 1. FIDS VS transducer cross-section (not to scale).

The VS is installed using four bolts which are inserted from the interior of the sensor through the mounting holes and screwed into tapped holes in the surface to be mounted to. The bolts are tightened down to clamp the mounting plate firmly to the surface.

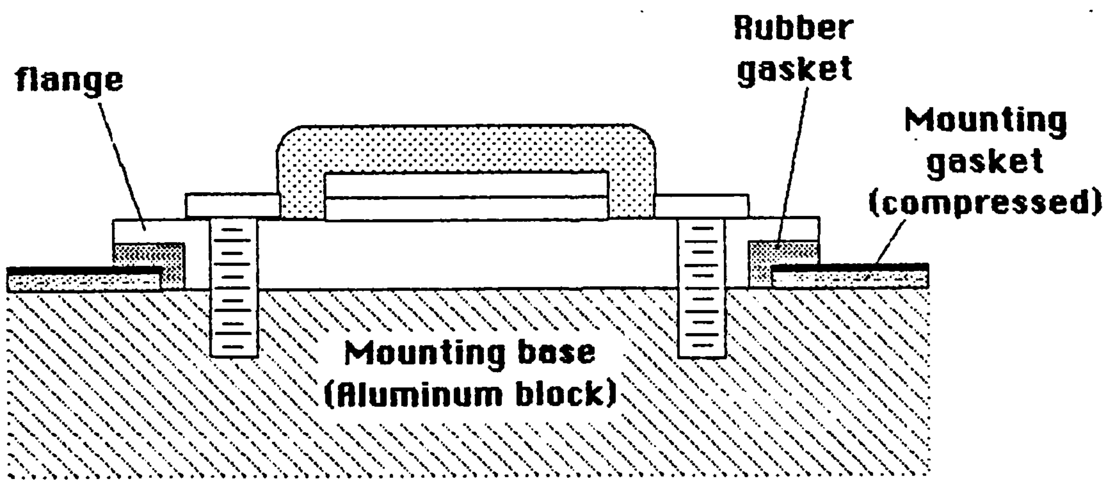
2.2.1.2 Mounting base. The VS transducer mounting plate by itself has natural resonant frequencies determined by the dimensions of the plate. When the sensor is tightly coupled to a surface, as in a typical installation, the large mass of the surface shifts the resonant frequencies outside the detection bands of the sensor. Because a small exciter would not itself restrict these resonances, some other means of limiting their effect on the sensor's response is required. Therefore, any proposed test system using a low mass exciter would also require an adjunct mounting fixture, such as a large mass, to dampen or eliminate these effects and achieve a smooth, well defined response. For the test fixture to be used in this study an aluminum block will serve as the large mass. The VS transducer mounting plate will be bolted to this block to limit the plate's spurious resonances.

2.2.1.3 Damping for flanges and VS enclosure. There is yet another source of spurious resonances in the transducer mounting plate which will not be damped by the aluminum block described above. In a previous study of the vibration sensor it had been observed that the flanges on the mounting plate (see fig. 1) contribute strong natural resonances to the sensor's response. The rubber gasket in contact with the flanges does not sufficiently damp the resonances because it is not tightly coupled to the flanges.

In order to damp the flange resonances it was necessary to clamp the flanges tightly. This was done by using a gasket between the sensor enclosure and the mounting base (aluminum block) as shown in figure 2. When the mounting bolts are tightened the gasket on the mounting base will be compressed against the sensor enclosure, forcing it against the sensor gasket and thereby clamping the flanges. By clamping tightly to the enclosure this arrangement will also help isolate the transducer from resonances related to that enclosure.



(a) Before mounting



(b) After mounting

Figure 2. Detail of damping method for VS test fixture

2.2.2 Localized exciter.

2.2.2.1 Construction. The operation of the exciter, like the vibration sensor, is based on a piezo-electric ceramic material. In the sensor, the piezo-electric material is alternately compressed and expanded by vibrations of the mounting surface causing the material to generate a voltage. In the exciter, a voltage will be applied to the piezo-electric material causing it to expand and contract (vibrate).

The ceramic material used in this exciter was type 5A lead-zirconium-titanate made by Vernitron (type PZT-5A). The exciter design consisted of a one inch diameter disk of the piezoelectric ceramic, approximately 1/4" thick, cemented between a 1/4" thick steel disk and an aluminum disk, approximately 1/8" thick, which served as a mounting base (see fig. 3). The diameter of the metal disks was the same as the ceramic disk.

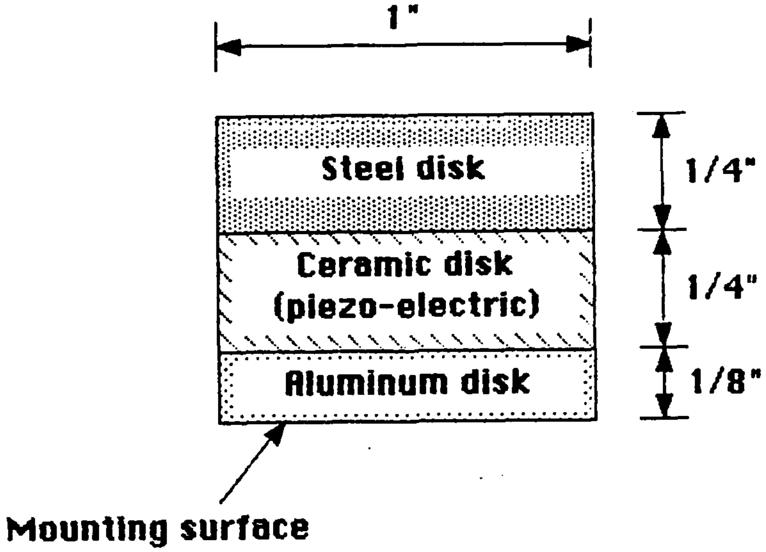


Figure 3. Vibration exciter
(not to scale)

With a given electrical input, the mechanical displacement output of a piezoelectric element is approximately proportional to thickness. A 1/4" element provides adequate drive, though any thickness above 0.1" would probably have sufficed. The element diameter, also not particularly critical, needs to be large enough to provide excitation over the surface area of the transducer under test, in this case about 1". The exciter used in these tests was fabricated from a commercially available ceramic element costing less than $5.

Using the above dimensions, the first resonant frequency of the spring-mass system formed by the piezoelectric element and metal plates was calculated to be approximately 120 kHz, well above the region of interest. These calculations were confirmed by frequency response tests using the shock-test apparatus.

Several low-mass exciter designs were considered, including a single exciter element and a multiple exciter array. The multiple array (4 or 6 exciter elements mounted to a common drive plate) yielded greater output and lower drive impedance; however, the single element provided more than adequate drive and was much simpler to fabricate. Therefore, only the single element design was chosen for further consideration.

2.2.2.2 Coupling to sensor. The exciter element was held against the transducer plate by a stiff spring. A hole drilled in the mounting base allowed access to the mounting plate for the exciter (see fig. 4). A cup was fabricated to hold the exciter and for the spring to push against. The bottom of the hole in the mounting base was closed with a metal plate to retain the spring/exciter assembly (see fig. 5). With the spring/exciter assembly positioned in the hole the top surface of the exciter was above the level of the mounting base (fig. 6). When the sensor was bolted to the base the spring was compressed thereby forcing the exciter against the surface of the mounting plate and providing a very tight coupling. To further improve the coupling, a small amount of light oil was applied to the surface of the exciter before the sensor was attached. More detailed drawings of the test fixture are given in appendix C.

Figure 4. Aluminum mounting block showing access hole for exciter

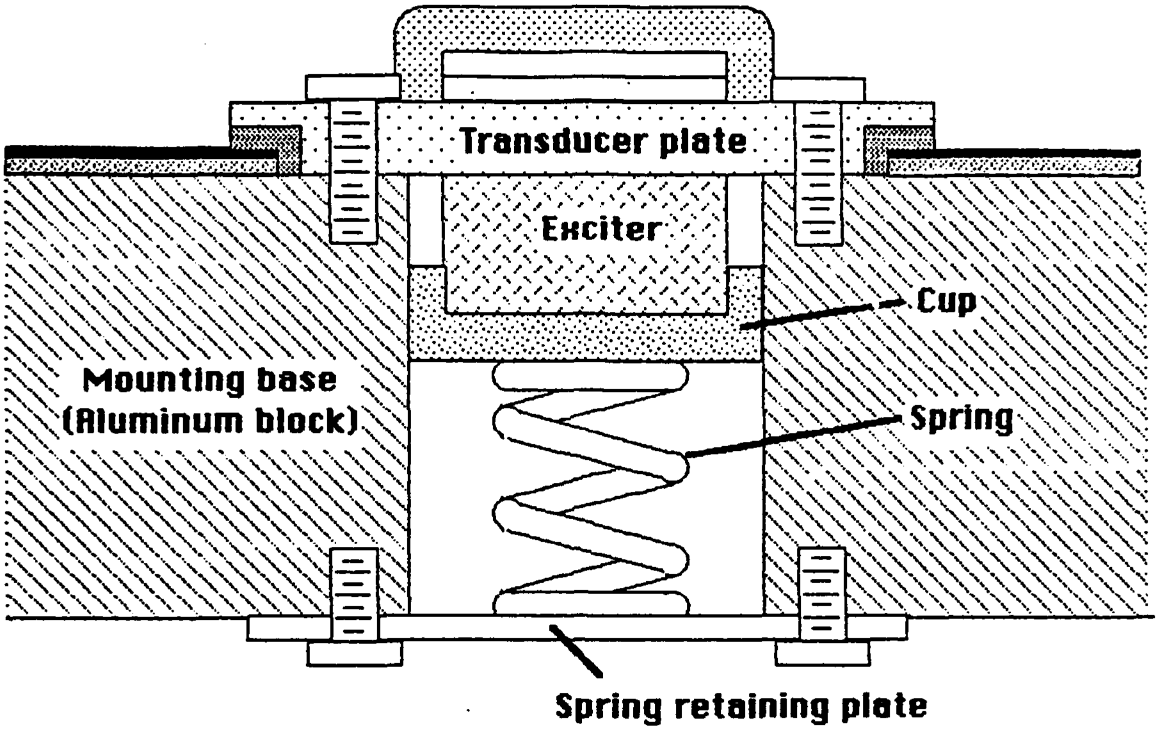


Figure 5. Detail of exciter coupling method

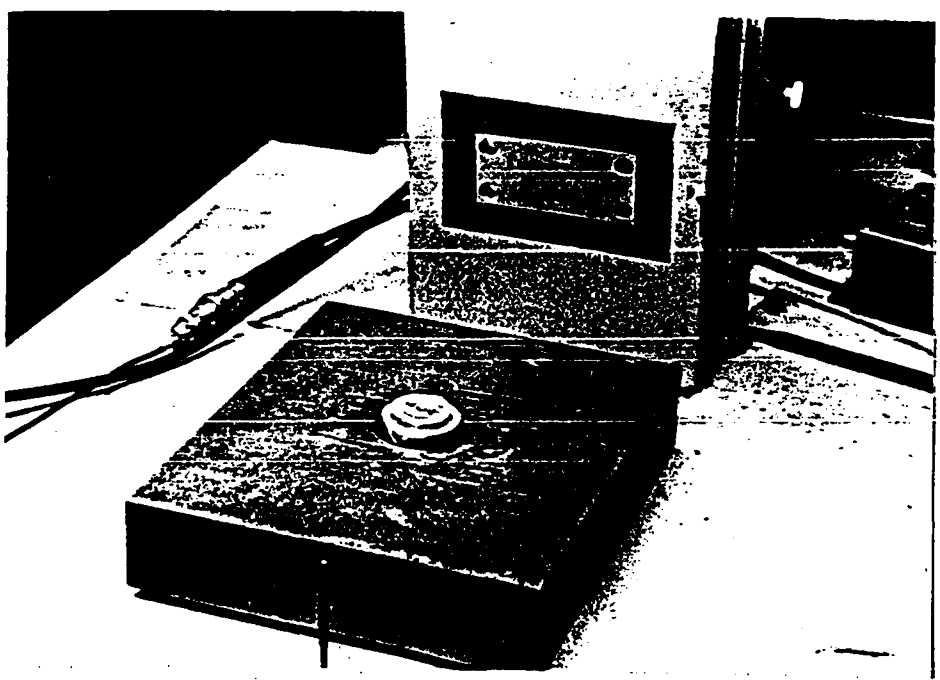


Figure 6. Mounting base with exciter

2.2.3 Generation and analysis of test signals. The equipment used to characterize the response of the test fixture is shown in figure 7. A tracking oscillator generated a signal which was amplified and used to drive the exciter. This signal was swept over a frequency range of 0 to 20 kHz which covers the FIDS VS range. A spectrum analyzer was used to display the output response of the VS transducer as a function of frequency. This setup displayed the transfer function of the test fixture/VS system. This transfer function was used to identify any spurious system resonances which needed to be suppressed.

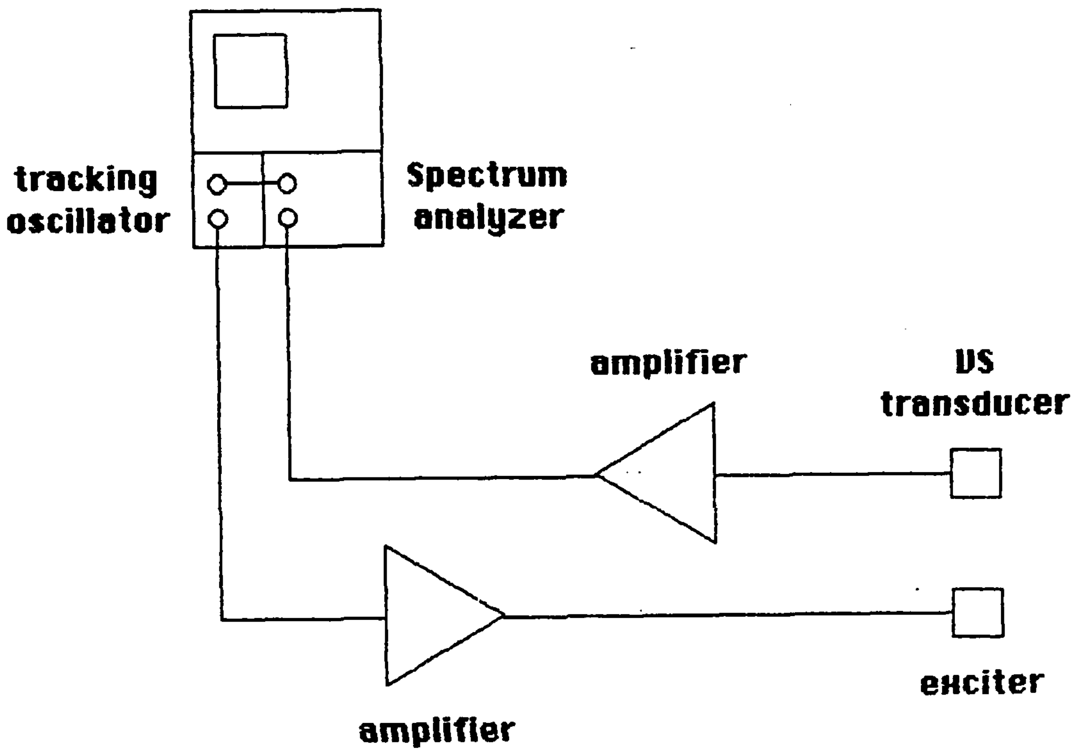


Figure 7. Electrical connections for test fixture

2.3 Test results. As stated above, the test equipment was setup to monitor the transfer function of the test fixture/vibration sensor system. The objective of the tests was to determine if there were features of the fixture or sensor which would cause spurious resonant responses. Steps could then be taken to eliminate the spurious resonances. An area of particular concern was the damping of the transducer plate flanges and the sensor enclosure. This is highly dependent on the selection of an appropriate gasket material for use between the sensor and the mounting base. Therefore, testing different gasketing methods was a significant part of the study.

2.3.1 Black foam. The first material tried was a 1/2" thick piece of black foam, military specification MIL-R-6130 type 2, group C, medium (see fig. 9). With the sensor bolted to the mounting base (thereby compressing the foam), the signal to the exciter was swept from 0 to 20 kHz. Figure 10 shows the output spectrum from the vibration sensor transducer as displayed on the spectrum analyzer. The scale of the spectrum analyzer's display was 2 kHz per major horizontal division and 10 dB per major vertical division. As can be seen from the figure, the response is not flat but rather rises to a peak at 14 kHz with a local peak at 6 kHz. Also the response is not smooth but jagged. It was thought that the reason for the poor response of the foam was that it was not stiff enough to damp the spurious resonances. It was decided to use a stiffer gasket made of rubber.

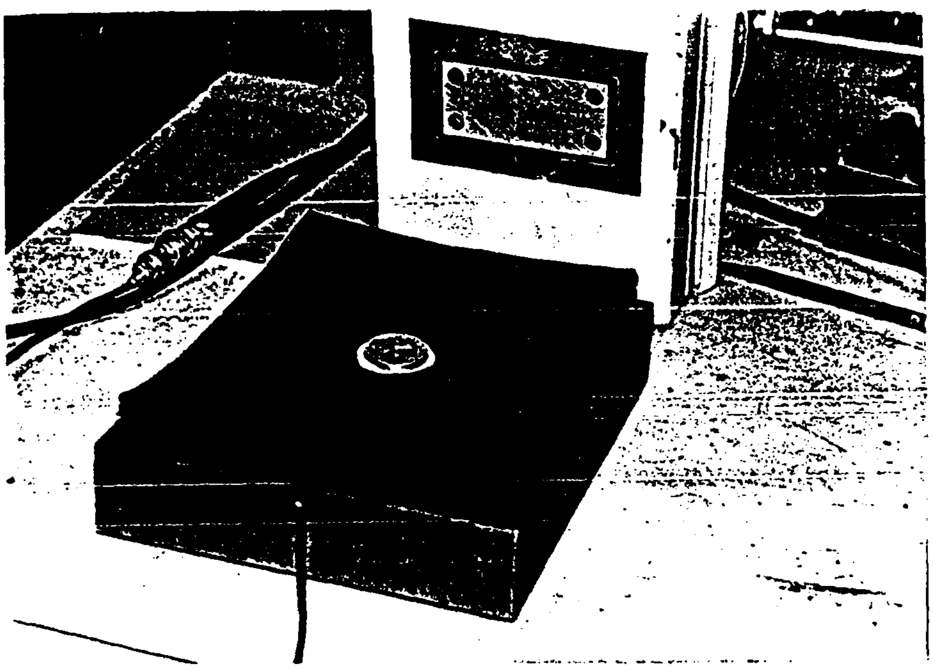


Figure 9. Black foam

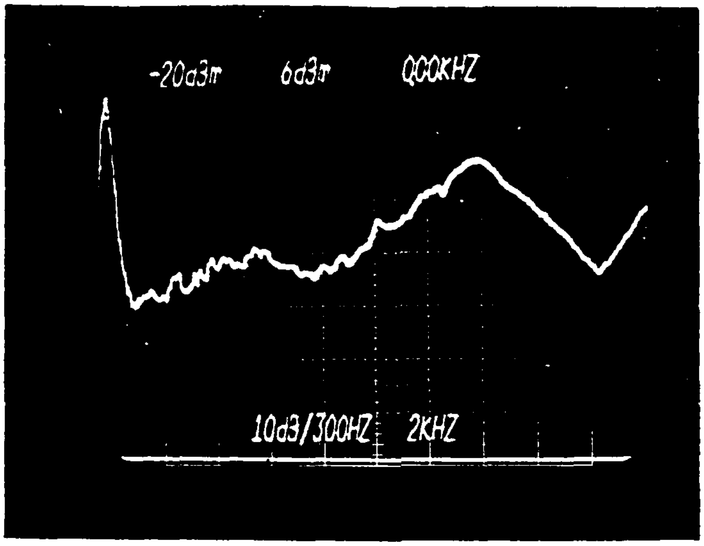


Figure 10. Response with black foam

2.3.2 Single gasket. A single layer of 1/8" thick rubber gasket was substituted for the foam used previously. This gasket was cut from an anti-static mat made by Benstat (0.06 workmat). Its response curve (fig. 11) was even worse than the foam. There were many peaks and nulls in the response such as at 4, 6 and 8 kHz. The lack of damping was probably due to the thinness of the material. Because of this thinness, the gasket was not compressed much when the sensor was attached to the mounting base and therefore the gasket did not exert much force on the sensor enclosure and transducer flanges. To confirm this it was decided to run the test using two layers of the rubber gasket.

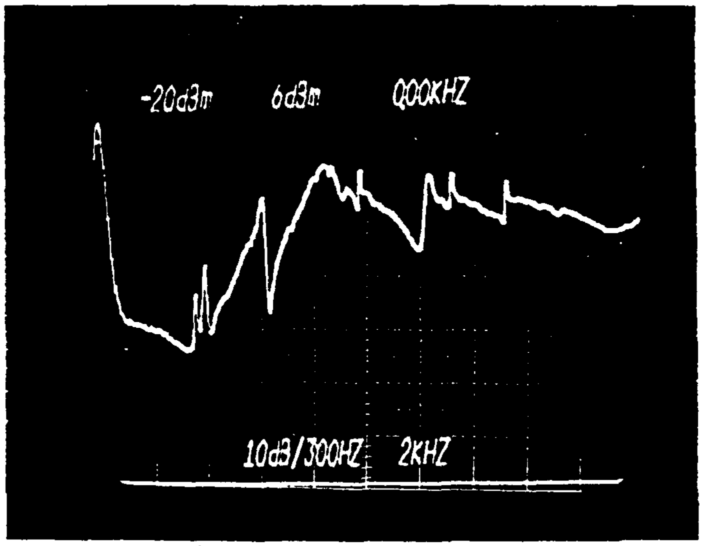


Figure 11. Response with single layer of rubber gasket

2.3.3 Double gasket. Shown in figure 12 is the test fixture with two layers of the gasket material. The response curve with this configuration (fig. 13) showed a great improvement over the tests with the single rubber gasket and the foam. Although the response still rises to a peak at approximately 14 kHz it is much smoother than the best previous response using the foam (fig. 10). However, there are still significant resonances at 2 and 4 kHz.

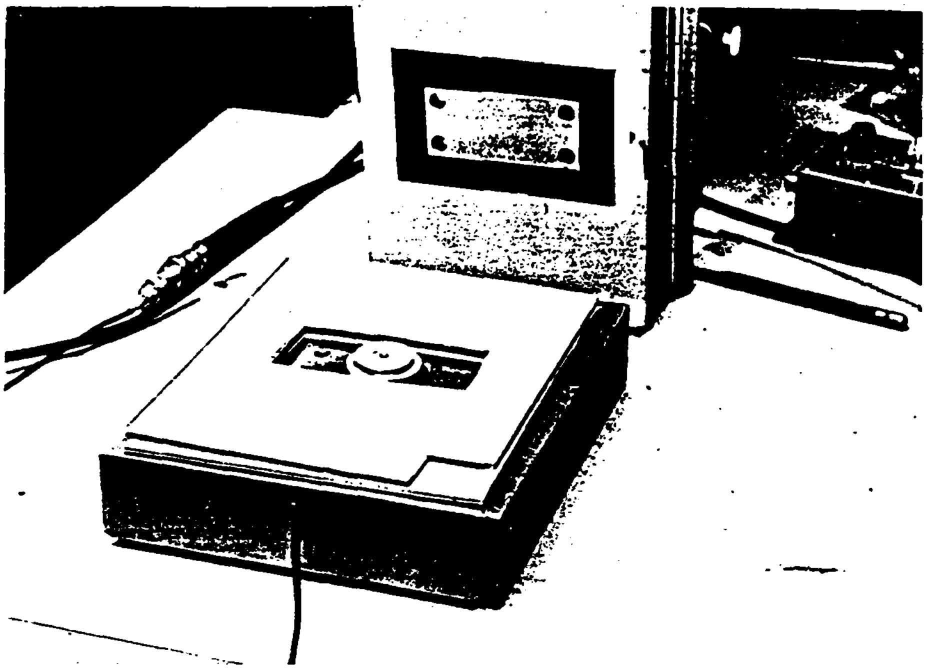


Figure 12. Double layer of rubber gasket

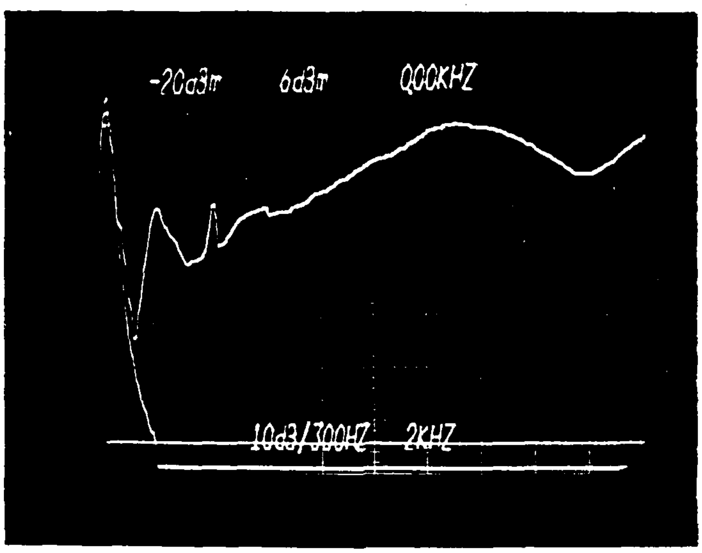


Figure 13. Response with double layer of rubber gasket

2.3.4 Spring damping. Tracking down the above mentioned resonances was done in large part by hand. Various parts of the test fixture and sensor that were suspected of being the cause of the resonances were held or pressed on to damp them. By observing the response curve as this was done the source of the resonances could be identified.

Using this method to eliminate other possibilities the source of the resonances at 2 and 4 kHz was finally discovered to be the spring which held the exciter against the sensor. After the spring was damped with foam the response curve was as shown in figure 14. As can be seen, the resonances at 2 and 4 kHz have been severely attenuated by damping the spring.

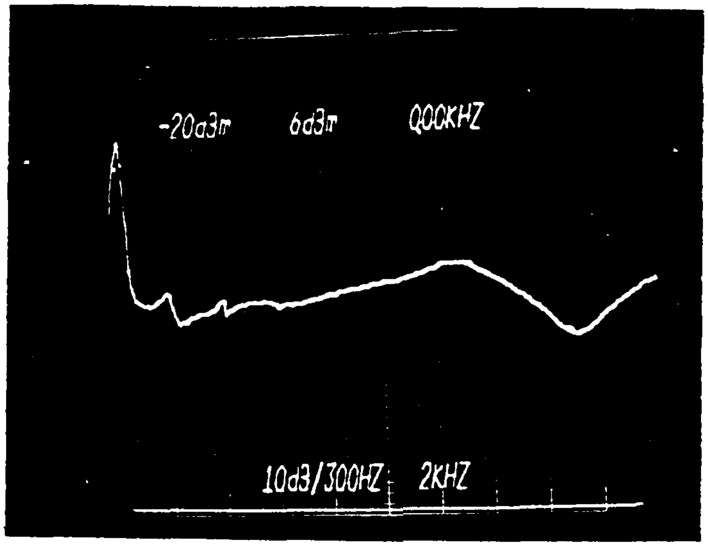


Figure 14. Response with spring damped

The 20 dB drop in the peak value of the response (at 14 kHz) between figures 13 and 14 had nothing to do with damping the spring. This change in the peak value occurred even if the sensor was just remounted on the test fixture and no other changes made. The cause of this problem is possibly related to the characteristics of the mounting gasket and will need to be analyzed in any further investigations.

SECTION 3. APPENDICES

APPENDIX A

Statement of Work

Intrusion Detection System Test Methodology

11 March 1987

1.0 INTRODUCTION:

There currently exists a performance deficiency in the testing of vibration sensors. Specifically, there does not exist a reliable and repeatable method for testing the higher frequencies covered by some of these sensors (> 10 kHz). The major difficulty is in finding an exicitor mechanism (e.g., shake table) that can handle the combination of high frequency and acceleration necessary. The problem is exacerbated by the necessity of testing the entire sensor as a unit instead of just the transducer. This increases the mass that must be accelerated and constrains the physical connection between the tester and sensor.

2.0 WORK DESCRIPTION:

This study will describe the design of an excitor mechanism for stimulating a vibration sensor. The FIDS vibration sensor will be used as the target sensor to establish design goals for the excitor. At a minimum the excitor will be capable of generating the signals necessary to verify the performance of the FIDS vibration sensor as given in its purchase description.

A final report will be generated documenting the design and use of the excitor. The report will include discussion of most likely sources of error and caveats when using the excitor. In addition, the report will include recommendations for a vibration test fixture based on the excitor.

3.0 PERIOD OF PERFORMANCE:

2 Jan 87 through 30 Sep 87

4.0 DELIVERABLES:

a. Progress Report: An informal letter report covering accomplishments for the period of 60 days following acceptance of the MIPR.

b. Final Report: A formal report describing the investigation and results to include recommendations for further engineering analysis and test systems development.

APPENDIX B

Definition of Terms

The following is a definition of terms and abbreviations used in this report:

Exciter - a device which produces mechanical vibration in order to drive or "excite" the VS transducer for test purposes.

Sensing element - the piezoelectric ceramic element used in the VS transducer to convert mechanical energy (vibration) into an electrical signal.

FIDS - Facility Intrusion Detection System. A standardized intrusion detection system being developed by the Army for all the services. Included in FIDS is a family of six intrusion sensors, one of which is the vibration sensor.

VS - the FIDS Vibration Sensor. This refers to the complete assembly, including circuit card and steel enclosure.

VS transducer - as used in the FIDS VS. It consists of an aluminum mounting plate, piezoelectric sensing/stimulus element, and elastomeric potting compound. This refers to the current FIDS production model, not the "new" vibration transducer (see below).

APPENDIX C

Test fixture drawings

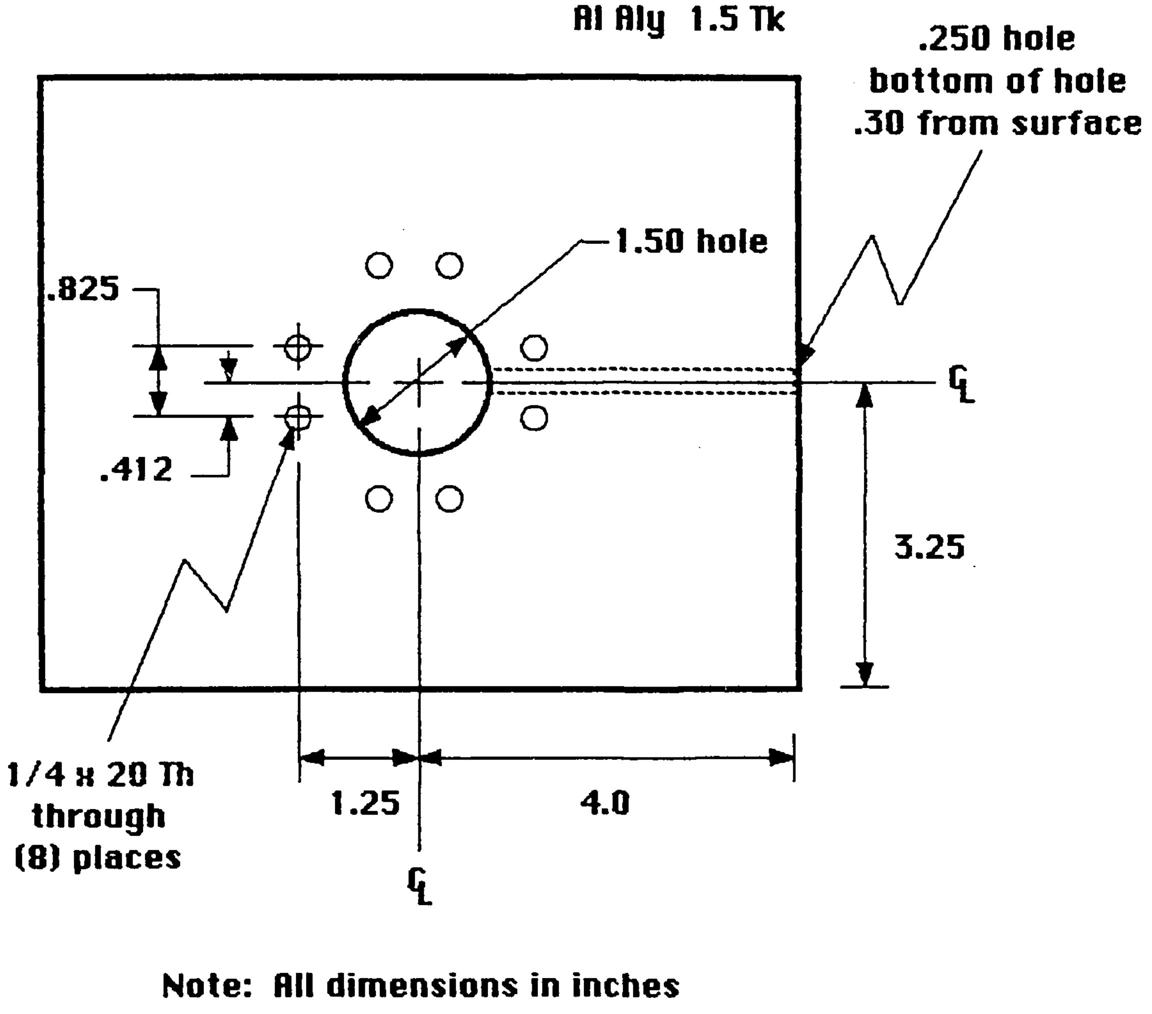


Figure C-1. Aluminum mounting plate

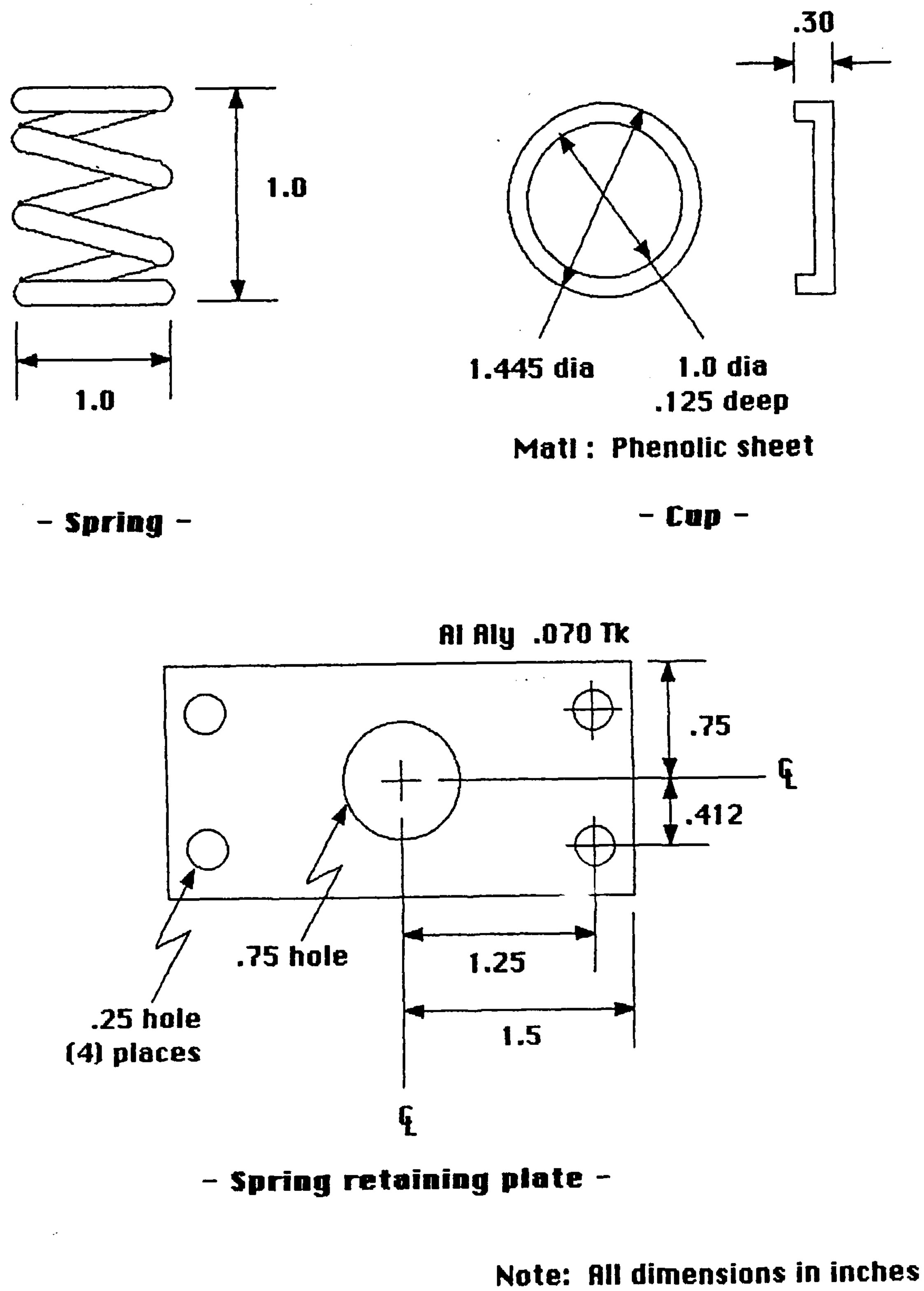


Figure C-2. Spring, cup and spring retaining plate

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